

# Very High Energy Considerations

B.G. Sidharth

International Institute for Applicable Mathematics & Information Sciences  
Hyderabad (India) & Udine (Italy)

B.M. Birla Science Centre, Adarsh Nagar, Hyderabad - 500 063 (India)

## Abstract

We revisit high energy Fermions and their behaviour, in the light of latest ideas from Quantum Gravity approaches and also from an alternative view. Some new consequences are discussed. All this would be important in view of the fact that the LHC has already attained  $7TeV$  and hopefully will attain its full energy  $14TeV$  by sometime in 2013. We also examine some extra relativistic effects like the recently discovered super luminal neutrino and the nature of gravitation in this context.

## 1 Introduction

The LHC in Geneva is already operating at a total energy of  $7TeV$  and hopefully after a pause in 2012, it will attain its full capacity of  $14TeV$  in 2013. These are the highest energies achieved todate in any accelerator. It is against this backdrop that it is worthwhile to revisit very high energy collisions of Fermions (Cf. also [1]). We will in fact examine their behaviour at such energies.

To get further insight, let us consider the so called Feshbach-Villars formulation [2] and analyze the problem from this point of view rather than that of conventional Field theory. In this case with an elementary transformation, the equations for the components  $\psi$  and  $\chi$  of the Dirac wave function can be written as

$$\begin{aligned} i\hbar(\partial\phi/\partial t) &= (1/2m)(\hbar/i\nabla - eA/c)^2(\phi + \chi) \\ &\quad + (e\phi + mc^2)\chi \end{aligned}$$

$$i\hbar(\partial\chi/\partial t) = -(1/2m)(\hbar/i\nabla - eA/c)^2(\phi + \chi) + (e\phi - mc^2\phi. \quad (1)$$

What Feshbach and Villars did was give a particle interpretation to the Klein-Gordon and Dirac equations without invoking field theory or the Dirac sea. In this case  $\phi$  represents the "low energy" solutions, that is the normal solution and  $\chi$  represents the "high energy" solutions. It must be remembered that at our usual energies it is the wave function  $\phi$ , the so called positive energy solution that dominates,  $\chi$  being of the order of  $v^2/c^2$  of  $\phi$ . On the other hand at very "high energies"  $\chi$  the so called negative energy solution dominates. Feshbach and Villars identified these two solutions with particles and antiparticles respectively. We have

$$\Psi = \begin{pmatrix} \phi_0(p) \\ \chi_0(p) \end{pmatrix} e^{i/\hbar(p \cdot x - Et)}$$

$$\Psi = \Psi_0(p) e^{i/\hbar(p \cdot x - Et)} \quad (2)$$

We consider separately the positive and negative values of  $E$  (coming from (2)), viz.,

$$E = \pm E_p; \quad E_p = [(cp)^2 + (mc^2)^2]^{\frac{1}{2}}. \quad (3)$$

The solutions associated with these two values of  $E$  are

$$\phi_0^{(+)} = \frac{E_p + mc^2}{2(mc^2 E_p)^{\frac{1}{2}}}$$

$$\chi_0^{(+)} = \frac{mc^2 - E_p}{2(mc^2 E_p)^{\frac{1}{2}}},$$

for  $E = E_p$  and

$$\phi_0^{(-)} = \frac{mc^2 - E_p}{2(mc^2 E_p)^{\frac{1}{2}}}$$

$$\chi_0^{(-)} = \frac{E_p + mc^2}{2(mc^2 E_p)^{\frac{1}{2}}},$$

for  $E = -E_p$ .

As is well known the positive solution ( $E = E_p$ ) and the negative solution ( $E = -E_p$ ) represent solutions of opposite charge. It is also well known that in the non relativistic limit the  $\chi$  components are reduced as mentioned with

respect to the  $\phi$  components, by the factor  $(p/mc)^2$ . We also mention the well known fact that a meaningful subluminal velocity operator can be obtained only from the wave packets formed by positive energy solutions. However the positive energy solutions alone do not form a complete set, unlike in the non relativistic theory. This also means that a point description in terms of the positive energy solutions alone is not possible for the K-G (or the Dirac) equation, that is for the position operator,

$$\delta(\vec{X} - \vec{X}_0)$$

In fact the eigen states of this position operator include both positive and negative solutions. All this is well known (Cf.ref.[2, 3, 4]).

This matter was investigated earlier by Newton and Wigner too [5] from a slightly different angle. Some years ago the author revisited this aspect from yet another point of view [6] and showed that this is symptomatic of noncommutativity which is exhibited by

$$[x_i, x_j] = O(l^2) \cdot \Theta_{ij}$$

is related to spin and extension. The noncommutative nature of spacetime has been a matter of renewed interest in recent years particularly in Quantum Gravity approaches. At very high energies, it has been argued that [7] there is a minimum fuzzy interval, symptomatic of a non commutative spacetime, so the usual energy momentum relation gets modified and becomes [8]

$$E^2 = p^2 + m^2 + \alpha l^2 p^4 \quad (4)$$

the so called Snyder-Sidharth Hamiltonian [9, 10, 11, 12]. It has been argued that for fermions  $\alpha > 0$ . Using (4) it is possible to deduce the ultrarelativistic Dirac equation [13, 14]

$$(D + \beta l p^2 \gamma^5) \psi = 0 \quad (5)$$

$\beta = \sqrt{\alpha}$ . In (5)  $D$  is the usual Dirac operator while the extra term appears due to the new dispersion relation (4).

We now consider two cases:

**Case 1:** As indicated above  $\alpha$  is positive. It is known that [3, 15], in this case equation (5) can be written in Hamiltonian form

$$-\gamma_0 p^0 \psi = (\bar{D} + i \alpha l p^2 \gamma_5) \psi \quad (6)$$

where  $\bar{D} \equiv \sum_i \gamma^i p_i$ . Further it is well known that the Hamiltonian is given by [3]

$$H = \imath \gamma_5 \vec{\Sigma} \cdot \vec{p} = \imath \gamma_5 |\vec{p}| s(\vec{p}) \quad (7)$$

It can be seen from (7) that the Dirac particle acquires an additional mass. However what is very interesting is that the extra mass term is not invariant under parity owing to the presence of  $\gamma_5$ . Indeed as we know from the theory of Dirac matrices [4]

$$P \gamma_5 = -P \gamma_5 \quad (8)$$

In the case of a massless Dirac particle, it was argued that this leads to the mass of the neutrino [10].

Thus the mass  $m$  gets split into  $m + m'$  and  $m - m'$  with two states,  $\Psi_L$  and  $\Psi_R$ . Remembering that a dominant  $\phi$  and a dominant  $\chi$  respectively represent particle and antiparticle in this Feshbach-Villars formulation and also remembering that under reflection, as is well known,

$$\phi \rightarrow \phi, \quad \chi \rightarrow -\chi \quad (9)$$

we can see that this means that the particle and antiparticle have different masses, namely  $m + m'$  and  $m - m'$ . Indeed this conclusion was anticipated earlier [16]. The difference would be minute but in principle can be observed. Already there have been reports of such mass asymmetry being observed in the MINOS Fermi Lab experiment with neutrinos and anti neutrinos [17]. What the MINOS team recorded was a difference in the  $\Delta m^2$  value for neutrinos and anti neutrinos by as much as forty percent. It is expected that more definitive results would be available by 2012.

**Case 2:** For completeness we also consider the case  $\alpha < 0$ . We can see from (5) that the Hamiltonian now becomes non Hermitian and takes on an extra term (Cf.ref.[1]):

$$H = M - \imath N \quad (10)$$

where  $M$  is the usual Hamiltonian and  $N$  is now Hermitian (Cf.[15]), that is,  $M$  and  $N$  are real. This indicates a decay (remembering that the particle has been accelerated to ultra-high energies). With the modified Dirac equation (5) in place of the usual Dirac equation, we can now treat the two states considered above viz.,

$$\psi_L, \psi_R$$

as forming a two state system in this subspace of the Hilbert space of all states where the two components decay at different rates, in general as we

will see below. The theory of such two state systems is well known [18]. In fact the two states would now be given by

$$\psi_{L,R}(t) = e^{\imath Mt} \cdot e^{-Nt} \psi_{L,R}(0) \quad (11)$$

where the left side refers to the state of time  $t$  and the right side wave function to the time  $t = 0$  (Cf. also [19]). We can write the Hamiltonian (10) above for the two state as

$$H_{eff} = \begin{pmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{pmatrix} = M - \imath N = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} - \imath \begin{pmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{pmatrix}$$

where-by virtue of the pulled out  $\imath$ -both  $M$  and  $N$  are Hermitian. An additional constraint, namely  $H_{11} = H_{22}$ , comes from the CPT theorem. Let us continue with the two state analysis.

The evolution equation (in this sub space),

$$H|\psi\rangle = \imath \frac{d}{dt} |\psi\rangle$$

yields the usual solution

$$|\psi_{H,L}\rangle(t) = \exp[-\imath H_{H,L}] |\psi_{H,L}\rangle(0)$$

where  $H_{H,L}$  denotes the eigenvalues of  $H$ , which are under the assumption of CPT symmetry given as is well known, by

$$H_{H,L} = H_{11} \pm \sqrt{H_{12}H_{21}}$$

and  $|\psi_{H,L}\rangle$  are eigenstates of the form

$$|\psi_{H,L}\rangle = p|\psi^0\rangle \mp q|\bar{\psi}^0\rangle$$

with

$$\frac{q}{p} = -\frac{H_H - H_L}{2H_{12}}$$

Rewriting the time-dependent solution using  $H_{H,L} = M_{H,L} - \imath N_{H,L}$  with real  $M$  and  $N$ , we get

$$|\psi_{H,L}\rangle(t) = \exp[-N_{H,L}] \exp[-\imath M_{H,L}](t) |\psi_{H,L}\rangle(0)$$

This represents two Fermions (one perhaps heavier with mass  $M_H$ , one lighter with mass  $M_L$ ), decaying with (generally different) decay constants  $N_{H,L}$ . The mean mass  $M = \frac{1}{2}(M_H + M_L)$  and  $\Delta M = M_H - M_L$ .

It has been pointed out that equations like (7) and the following applied to neutrinos which are massless suggests one (or more) neutrinos. This is brought out more clearly in the above. Remarkably there seems to be very recent confirmation of such an extra or sterile neutrino [20].

The above discussion brings out ultra high energy effects in Fermionic behavior. Already equation (4) shows modifications to Lorentz symmetry, as has been discussed in detail in several places, for example (Cf.ref.[8, 9] and references therein). This exposes the limits of strict special relativistic considerations.

## 2 Extra Relativistic Effects

It has just been announced that the OPERA (Oscillation Project with Emulsion Tracking Apparatus) experiment, 1400 meters underground in the Gran Sasso National Laboratory in Italy has detected neutrinos travelling faster than the speed of light, which has been a well acknowledged speed barrier in physics. This limit is 299,792,458 meters per second, whereas the experiment has detected a speed of 299,798,454 meters per second. In this experiment neutrinos from the CERN Laboratory 730 kilometers away in Geneva were observed. They arrived 60 nano seconds faster than expected, that is faster than the time allowed by the speed of light. The experiment has been measured to  $6\sigma$  level of confidence, which makes it a certainty [21]. However it is such an astounding discovery that the OPERA scientists would like further confirmation from other parts of the world. In 2007 the MINOS experiment near Chicago did find hints of this superluminal effect. Nevertheless scientists wait with bated breath to confirm this earth shattering discovery.

It must be reported that the author had predicted such deviations from Einstein's Theory of Relativity, starting from 2000. This work replaces the usual Einstein energy momentum formula with the modified expression (the so called Snyder-Sidharth Hamiltonian (4)),

$$E^2 = p^2 c^2 + m^2 c^4 + \alpha l^2 p^4$$

where  $l$  is a minimum length like the Planck length and  $\alpha$  is positive for fermions or spin half particles like neutrinos [22, 23, 9, 24, 7]. The above

formula is based on considerations of a non differentiable spacetime at ultra high energies. It shows that the energy at very high energies for fermions is greater than that given by the relativity theory so that effectively the speed of the particle is slightly greater than that of light. For example, if in the usual formula, we replace  $c$  by  $c + c'$ , then, comparing with the above we would get:

$$c' = \alpha l^2 p^4 \cdot [4m^2 c^3 + 2p^2 c]^{-1}$$

The difference is slight, but as can be seen is maximum for the lightest fermions, viz., neutrinos which are in any case already travelling with the velocity  $c$ .

### 3 Ultra High Energy Particles

Let us look at all this differently. Following Weinberg [25] let us suppose that in one reference frame  $S$  an event at  $x_2$  is observed to occur later than one at  $x_1$ , that is,  $x_2^0 > x_1^0$  with usual notation. A second observer  $S'$  moving with relative velocity  $\vec{v}$  will see the events separated by a time difference

$$x_2'^0 - x_1'^0 = \Lambda_\alpha^0(v)(x_2^\alpha - x_1^\alpha)$$

where  $\Lambda_\alpha^\beta(v)$  is the "boost" defined by or,

$$x_2'^0 - x_1'^0 = \gamma(x_2^0 - x_1^0) + \gamma\vec{v} \cdot (x_2 - x_1)$$

and this will be negative if

$$v \cdot (x_2 - x_1) < -(x_2^0 - x_1^0) \tag{12}$$

We now quote from Weinberg [?]:

"At first sight this might seem to raise the danger of a logical paradox. Suppose that the first observer sees a radioactive decay  $A \rightarrow B + C$  at  $x_1$ , followed at  $x_2$  by absorption of particle  $B$ , for example,  $B + D \rightarrow E$ . Does the second observer then see  $B$  absorbed at  $x_2$  before it is emitted at  $x_1$ ? The paradox disappears if we note that the speed  $|v|$  characterizing any Lorentz transformation  $\Lambda(v)$  must be less than unity, so that (12) can be satisfied only if

$$|x_2 - x_1| > |x_2^0 - x_1^0| \tag{13}$$

"However, this is impossible, because particle  $B$  was assumed to travel from  $x_1$  to  $x_2$ , and (13) would require its speed to be greater than unity, that is, than the speed of light. To put it another way, the temporal order of events at  $x_1$  and  $x_2$  is affected by Lorentz transformations only if  $x_1 - x_2$  is spacelike, that is,

$$\eta_{\alpha\beta}(x_1 - x_2)^\alpha(x_1 - x_2)^\beta > 0$$

whereas a particle can travel from  $x_1$  to  $x_2$  only if  $x_1 - x_2$  is timelike, that is,

$$\eta_{\alpha\beta}(x_1 - x_2)^\alpha(x_1 - x_2)^\beta < 0$$

"Although the relativity of temporal order raises no problems for classical physics, it plays a profound role in quantum theories. The uncertainty principle tells us that when we specify that a particle is at position  $x_1$  at time  $t_1$ , we cannot also define its velocity precisely. In consequence there is a certain chance of a particle getting from  $x_1$  to  $x_2$  even if  $x_1 - x_2$  is spacelike, that is,  $|x_1 - x_2| > |x_1^0 - x_2^0|$ . To be more precise, the probability of a particle reaching  $x_2$  if it starts at  $x_1$  is nonnegligible as long as

$$(x_1 - x_2)^2 - (x_1^0 - x_2^0)^2 \leq \frac{\hbar^2}{m^2} \quad (14)$$

where  $\hbar$  is Planck's constant (divided by  $2\pi$ ) and  $m$  is the particle mass. (Such space-time intervals are very small even for elementary particle masses; for instance, if  $m$  is the mass of a proton then  $\hbar/m = w \times 10^{-14}cm$  or in time units  $6 \times 10^{-25}sec$ . Recall that in our units  $1sec = 3 \times 10^{10}cm$ .) We are thus faced again with our paradox; if one observer sees a particle emitted at  $x_1$ , and absorbed at  $x_2$ , and if  $(x_1 - x_2)^2 - (x_1^0 - x_2^0)^2$  is positive (but less than  $\hbar^2/m^2$ ), then a second observer may see the particle absorbed at  $x_2$  at a time  $t_2$  before the time  $t_1$  it is emitted at  $x_1$ ".

To put it another way, the temporal order of causally connected events cannot be inverted in classical physics, but in Quantum Mechanics, the Heisenberg Uncertainty Principle leaves a loop hole. To quote Weinberg again:

"There is only one known way out of this paradox. The second observer must see a particle emitted at  $x_2$  and absorbed at  $x_1$ . But in general the particle seen by the second observer will then necessarily be different from that seen by the first. For instance, if the first observer sees a proton turn into a neutron and a positive pi-meson at  $x_1$  and then sees the pi-meson and some other neutron turn into a proton at  $x_2$ , then the second observer must see the neutron at  $x_2$  turn into a proton and a particle of negative charge,



which is then absorbed by a proton at  $x_1$  that turns into a neutron. Since mass is a Lorentz invariant, the mass of the negative particle seen by the second observer will be equal to that of the positive pi-meson seen by the first observer. There is such a particle, called a negative pi-meson, and it does indeed have the same mass as the positive pi-meson. This reasoning leads us to the conclusion that for every type of charged particle there is an oppositely charged particle of equal mass, called its antiparticle. Note that this conclusion does not obtain in nonrelativistic quantum mechanics or in relativistic classical mechanics; it is only in relativistic quantum mechanics that antiparticles are a necessity. And it is the existence of antiparticles that leads to the characteristic feature of relativistic quantum dynamics that given enough energy we can create arbitrary numbers of particles and their antiparticles”.

As can be seen from the above, the two observers  $S$  and  $S'$  see two different events, viz., one sees, in this example the protons while the other sees neutrons. Moreover, this is a result stemming from (14), viz.,

$$0 < (x_1 - x_2)^2 - (x_1^0 - x_2^0)^2 (\leq \frac{\hbar^2}{m^2}) \quad (15)$$

The inequality (15) points to a reversal of time instants  $(t_1, t_2)$  as noted above. However, as can be seen from (15), this happens within the Compton wavelength.

Let us digress to classical theory for a moment.

i) From the above analysis it is clear that a localized particle requires both signs of energy. At relatively low energies, the positive energy solutions predominate and we have the usual classical type particle behaviour. On the other hand at very high energies it is the negative energy solutions that predominate as for the negatively charged counterpart or the anti particles. More quantitatively, well outside the Compton wavelength the former behaviour holds. But as we approach the Compton wavelength we have to deal with the new effects.

ii) To reiterate if we consider the positive and negative energy solutions given by  $\pm E_p$ , as in (??), then we saw that for low energies, the positive solution  $\phi_0$  predominates, while the negative solution  $\chi_0$  is  $\sim (\frac{v}{c})^2$  compared to the positive solution. On the other hand at very high energies the negative solutions begin to play a role and in fact the situation is reversed with  $\phi_0$  being suppressed in comparison to  $\chi_0$ . This can be seen from (??).

iii) We could now express the foregoing in the following terms: It is well

known that we get meaningful probability currents and subluminal classical type situations using positive energy solutions alone as long as we are at energies low enough such that we are well outside the Compton scale. As we near the Compton scale however, we begin to encounter negative energy solutions or these anti-particles.

From this point of view, we can mathematically dub the solutions according to the sign of energy ( $p_0/|p_0|$ ) of these states:  $+1$  and  $-1$ . This operator commutes with all observables and yet is not a multiple of unity as would be required by Schur's lemma, as it has two distinct eigen values. This is a superselection principle or a superspin with two states and can be denoted by the Pauli matrices. The two states would refer to the positive energy solutions and the negative energy solutions (Cf.refs.[26, 27]).

iv) We could now think along the lines of  $SU(2)$  and consider the transformation [28]

$$\psi(x) \rightarrow \exp\left[\frac{1}{2}ig\tau \cdot \omega(x)\right]\psi(x). \quad (16)$$

This leads to a covariant derivative

$$D_\lambda \equiv \partial_\lambda - \frac{1}{2}ig\tau \cdot \bar{W}_\lambda, \quad (17)$$

as in the usual theory, remembering that  $\omega$  in this theory is infinitesimal. We are thus lead to vector Bosons  $\bar{W}_\lambda$  and an interaction rather like the weak interaction. However we must bear in mind that this new interaction between particle and anti-particle [17] would be valid only within the Compton time, inside this Compton scale Quantum Mechanical bridge.

v) We have already seen that even given the Lorentz transformation, due to Quantum Mechanical effects, there could be an apparent inversion of events, though at the expense of the exact description of either observer. This has been brought out in Section 1 in the case of the observer seeing protons and another seeing neutrons. We now observe that in the above formulation for the wave function

$$\Psi = \begin{pmatrix} \phi \\ \chi \end{pmatrix},$$

where, as noted,  $\phi$  and  $\chi$  are, for the Dirac equation, each two spinors.  $\phi$  (or more correctly  $\phi_0$ ) represents a particle while  $\chi$  represents an antiparticle. So, for one observer we have

$$\Psi \sim \begin{pmatrix} \phi \\ 0 \end{pmatrix} \quad (18)$$

‘ and for another observer we can have

$$\Psi \sim \begin{pmatrix} 0 \\ \chi \end{pmatrix} \quad (19)$$

that is the two observers would see respectively a particle and an antiparticle. This would be the same for a single observer, if for example the particle’s velocity got a boost so that (27) rather than (26) would dominate after some-time.

Interestingly, just after the Big Bang, due to the high energy, we would expect, first (27) that is antiparticles to dominate, then as the universe rapidly cools, particles and antiparticles would be in the same or similar number as in the Standard Model, and finally on further cooling (26) that is particles or matter would dominate.

vi) We now make two brief observations, relevant to the above considerations. Latest results in proton-antiproton collisions at Fermi Lab have thrown up the  $B_s$  mesons which in turn have decayed exhibiting CP violations in excess of the predictions of the Standard Model, and moreover this seems to hint at a new rapidly decaying particle. Furthermore, in these high energy collisions particle to antiparticle and vice versa transformations have been detected.

## 4 Planck Oscillators

Some years ago [29], we explored some intriguing aspects of gravitation at the micro and macro scales. We now propose to tie up a few remaining loose ends. At the same time, this will give us some insight into the nature of gravitation itself and why it has defied unification with other interactions for nearly a century. For this, our starting point is an array of  $n$  Planck scale particles. As discussed in detail elsewhere, such an array would in general be described by [30]

$$l = \sqrt{n\Delta x^2} \quad (20)$$

$$ka^2 \equiv k\Delta x^2 = \frac{1}{2}k_B T \quad (21)$$

where  $k_B$  is the Boltzmann constant,  $T$  the temperature,  $r$  the extent and  $k$  is the analogues of the spring constant given by

$$\omega_0^2 = \frac{k}{m} \quad (22)$$

$$\omega = \left( \frac{k}{m} a^2 \right)^{\frac{1}{2}} \frac{1}{r} = \omega_0 \frac{a}{r} \quad (23)$$

We now identify the particles with Planck masses and set  $\Delta x \equiv a = l_P$ , the Planck length. It may be immediately observed that use of (22) and (21) gives  $k_B T \sim m_P c^2$ , which ofcourse agrees with the temperature of a black hole of Planck mass. Indeed, Rosen [31] had shown that a Planck mass particle at the Planck scale can be considered to be a Universe in itself with a Schwarzschild radius equalling the Planck length.

Whence the mass of the array is given by

$$m = m_P / \sqrt{n} \quad (24)$$

while we have,

$$l = \sqrt{n} l_P, \tau = \sqrt{n} \tau_P, \quad (25)$$

$$l_P^2 = \frac{\hbar}{m_P} \tau_P$$

In the above  $m_P \sim 10^{-5} gms$ ,  $l_P \sim 10^{-33} cm$  and  $\tau_P \sim 10^{-42} sec$ , the original Planck scale as defined by Max Planck himself. We would like the above array to represent a typical elementary particle. Then we can characterize the number  $n$  precisely. For this we use in (24) and (25)

$$l_P = \frac{2' G m_P}{c^2} \quad (26)$$

which expresses the well known fact that the Planck length is the Schwarzschild radius of a Planck mass black hole, following Rosen. This gives

$$n = \frac{l c^2}{G m} \sim 10^{40} \quad (27)$$

where  $l$  and  $m$  in the above relations are the Compton wavelength and mass of a typical elementary particle and are respectively  $\sim 10^{-12} cms$  and  $10^{-25} gms$  respectively.

Before coming to an interpretation of these results we use the well known result alluded to that the individual minimal oscillators are black holes or mini Universes as shown by Rosen [31]. So using the Beckenstein temperature formula for these primordial black holes [32], that is

$$kT = \frac{\hbar c^3}{8\pi G m}$$

we can show that

$$Gm^2 \sim \hbar c \quad (28)$$

We can easily verify that (28) leads to the value  $m = m_P \sim 10^{-5} \text{gms.}$  In deducing (28) we have used the typical expressions for the frequency as the inverse of the time - the Compton time in this case and similarly the expression for the Compton length. However it must be reiterated that no specific values for  $l$  or  $m$  were considered in the deduction of (28).

We now make two interesting comments. Cercignani and co-workers have shown [33, 34] that when the gravitational energy becomes of the order of the electromagnetic energy in the case of the Zero Point oscillators, that is

$$\frac{G\hbar^2\omega^3}{c^5} \sim \hbar\omega \quad (29)$$

then this defines a threshold frequency  $\omega_{max}$  above which the oscillations become chaotic. In other words, for meaningful physics we require that

$$\omega \leq \omega_{max}.$$

where  $\omega_{max}$  is given by (29). Secondly as we can see from the parallel but unrelated theory of phonons [35, 36], which are also bosonic oscillators, we deduce a maximal frequency given by

$$\omega_{max}^2 = \frac{c^2}{l^2} \quad (30)$$

In (30)  $c$  is, in the particular case of phonons, the velocity of propagation, that is the velocity of sound, whereas in our case this velocity is that of light. Frequencies greater than  $\omega_{max}$  in (30) are again meaningless. We can easily verify that using (29) in (30) gives back (28). As  $\hbar c = 137e^2$ , in a Large Number sense, (28) can also be written as,

$$Gm_P^2 \sim e^2$$

That is, (28) expresses the known fact that at the Planck scale, electromagnetism equals gravitation in terms of strength.

In other words, gravitation shows up as the residual energy from the formation of the particles in the universe via Planck scales particles.

The scenario which emerges is the following. Analogous to Prigogine cosmology [37, 38], from the dark energy background, in a phase transition Planck

scale particles are suddenly created. These then condense into the longer lived elementary particles by the above process of forming arrays. But the energy at the Planck scales manifests itself as gravitation, thereafter. We will further discuss this in the next section.

## 5 Discussion

Equation (27) can also be written as

$$\frac{Gm}{lc^2} \sim \sqrt{N} \quad (31)$$

where  $N \sim 10^{80}$  is the Dirac Large Number, viz., the number of particles in the universe. There are two remarkable features of (27) or (31) to be noted. The first is that it was deduced as a consequence in the author's 1997 cosmological model [24]. In this case, particles are created fluctuationally from the background dark energy. The model predicted a dark energy driven accelerating universe with a small cosmological constant. It may be recalled that at that time the prevailing paradigm was exactly opposite – that of a dark matter constrained decelerating universe. As is now well known, shortly thereafter this new dark energy driven accelerating universe with a small cosmological constant was confirmed conclusively through the observations of distant supernovae. It may be mentioned that the model also deduced other inexplicable relations like the Weinberg formula that relates the microphysical constants with a large scale parameter like the Hubble Constant:

$$m \approx \left( \frac{H\hbar^2}{Gc} \right)^{\frac{1}{3}} \quad (32)$$

While (32) has been loosely explained away as an accidental coincidence Weinberg [25] himself emphasized that the mysterious relation is in fact unexplained. To quote him, "In contrast (this) relates a single cosmological parameter (the Hubble Constant) to the fundamental constants  $\hbar, G, c$  and  $m$  and is so far unexplained."

The other feature is that (31) like (32) expresses a single large scale parameter viz., the number of particles in the universe or the Hubble constant in terms of purely microphysical parameters.

As we saw the scenario is similar to the Prigogine cosmology in which out of

what Prigogine called the Quantum Vacuum, or what today we may call Dark Energy background, Planck scale or Planck mass are created in a phase transition, very similar to the formation of Benard cells [39]. The energy at the Planck scale, given by (29) then gets distributed in the universe – amongst all the particles, as the Planck particles form these various elementary particles according to equations (20) to (25). This is brought out by the fact that equation (31) can also be written as the well known Eddington formula:

$$Gm^2/e^2 \sim \frac{1}{\sqrt{N}} \quad (33)$$

which was believed to be another ad hoc coincidence unrelated to (32). Equation (33) shows how the gravitational force over the cosmos is weak compared to the electromagnetic force. In other words the initial "gravitational energy" on the formation of the Planck scale particles, that is (28) is distributed amongst the various particles of the universe [40]. From this point of view while  $l, m, c$  etc. are indeed microphysical constants as Dirac characterized them,  $G$  is not. It is related to the Large Scale cosmos through the Dirac Number  $N$  of particles in the universe. This would also explain the Weinberg puzzle: In this case in equation (32), there are the large scale parameters namely  $G$  and  $H$  on right side of the equation.

Once we recognize this, we can easily see that unlike what was thought previously, the Weinberg formula (32) is in fact the same as the Dirac formula (33). To see this, we use in (32) two well known relations from cosmology (Cf.eg.[25]), viz.,

$$R \sim \frac{GM}{c^2} \text{ and } M = Nm$$

where  $R$  is the radius of the universe  $\sim 10^{28}cm$ ,  $M$  its mass  $\sim 10^{55}gm$  and  $m$  is as before the mass of a typical elementary particle. Then (32) will reduce to (33). Thus, there is only one relation – (32) or (33), and they express the fact that rather than being a microphysical parameter,  $G$  rather than representing a fundamental interaction is related to the large scale cosmos via either of these equations.

It must be observed that this conclusion resembles that of Sakharov [41], for whom Gravitation was a secondary force like elasticity.

## References

- [1] Sidharth, B.G. (2010). *Intl.J.Mod.Phys.E* 19 (10), 2010, pp.1-9.

- [2] Freshbach, H. and Villars, F. (1958). *Rev.Mod.Phys.* Vol.30, No.1, January 1958, pp.24-45.
- [3] S.S. Schweber. (1961). *An Introduction to Relativistic Quantum Field Theory* (Harper and Row, New York).
- [4] Bjorken, J.D. and Drell, S.D. (1964). *Relativistic Quantum Mechanics* (Mc-Graw Hill, New York), pp.39.
- [5] Newton, T.D. and Wigner, E.P. (1949). *Reviews of Modern Physics* Vol.21, No.3, July 1949, pp.400-405.
- [6] Sidharth, B.G. (2002). *Foundation of Physics Letters* 15 (5), 2002, pp.501ff.
- [7] Sidharth, B.G. (2008). *Thermodynamic Universe* (World Scientific, Singapore) and other references therein.
- [8] Sidharth, B.G. (2008). *Foundation of Physics* 38 (8), 2008, pp.695-706.
- [9] Sidharth, B.G. (2008). *Foundation of Physics* 38 (1), 2008, pp.89ff.
- [10] Sidharth B.G. (2010). *Int.J.Mod.Phys.E* 19 (1), 2010, pp.79-91.
- [11] Glinka L.A. (2008). *Apeiron* 2, April 2008; *arXiv hep-ph 0812.0551*.
- [12] Raoelina, A., and Rakotonirina, C. (2011). *EJTP* Vol.8 (25), May 2011.
- [13] Sahoo, S. (2010). *Ind.J.Pure and Appld.Phys.* 48, October 2010, pp.691-696.
- [14] Sidharth, B.G. (2005). *Int.J.Mod.Phys.E* 14 (6), 2005, 927ff.
- [15] Sidharth, B.G. (2010). *Int.J.Mod.Phys.E* 19 (11), 2010, pp.1-8.
- [16] Sidharth, B.G. (2010). *EJTP*, vol 7, (24), July 2010.
- [17] *Report: Physics World, IOP* June 18, 2010.
- [18] Feynman, R.P. (1965). *Feynman Lectures on Physics* Vol.III (Addison-Wesley Publishing Company, Reading, mass.). This gives a simple but illuminating discussion.



- [19] Widhalm, L. *Institute of High Energy Physics* (Vienna), private communication.
- [20] Roe, B. <http://physlinks.com>, to appear in *Phys.Rev.Lett.*.
- [21] Adam, T. et al., *arXiv 1109.4897*.
- [22] Sidharth, B.G. (2001). *Chaos, Solitons & Fractals* 12, 2001, pp.1449-1457.
- [23] Sidharth, B.G. (2001). *Chaotic Universe: From the Planck to the Hubble Scale* (Nova Science, New York), p.143.
- [24] Sidharth, B.G. (2005). *The Universe of Fluctuations* (Springer, Netherlands).
- [25] Weinberg, S. (1972). *Gravitation and Cosmology* (John Wiley & Sons, New York), p.61ff.
- [26] Sidharth, B.G. (2011). *Ultra High Energy Behaviour in New Advances in Physics* 5 (2), 2011; *arXiv 1103.1496.v3* March 2011.
- [27] Sidharth, B.G. *Negative Energy Solutions and Symmetries* to appear in *Int.J.Mod.Phys.E*; *arXiv 1104.011.v1* April 2011.
- [28] Taylor, J.C. (1976). *Gauge Theories of Weak Interactions* (Cambridge University Press, Cambridge) 1976.
- [29] Sidharth, B.G. (2006). *Int.J.Mod.Phys.A* 21(31), December 2006, pp.6315.
- [30] Jack Ng, Y. and Van Dam, H. (1994) *Mod.Phys.Lett.A*. 9, (4), pp.335–340.
- [31] Rosen, N. (1993). *Int.J.Th.Phys.*, 32, (8), pp.1435–1440.
- [32] Ruffini, R. and Zang, L.Z. (1983). *Basic Concepts in Relativistic Astrophysics* (World Scientific, Singapore), p.111ff.
- [33] Cercignani, C. (1998). *Found.Phys.Lett.* Vol.11, No.2, pp.189-199.
- [34] Cercignani, C., Galgani, L. and Scotti, A. (1972). *Phys.Lett.* 38A, pp.403.

- [35] Huang, K. (1975). *Statistical Mechanics* (Wiley Eastern, New Delhi), pp.75ff.
- [36] Reif, F. (1965). *Fundamentals of Statistical and Thermal Physics* (McGraw-Hill Book Co., Singapore).
- [37] Prigogine, I. (1996). *The End of Certainty* (The Free Press, New York), pg.172ff.
- [38] Edward P. Tryon (1973). *Is the Universe a Vacuum Fluctuation?* in *Nature* Vol.246, December 14 1973, pp.396-397.
- [39] Nicolis, G. and Prigogine, I. (1989). *Exploring Complexity* (W.H. Freeman, New York), p.10.
- [40] Sidharth, B.G. (2005). *Found.Phys.Lett.*,18(4),2005.
- [41] Sakharov, A.D. (1968). *Soviet Physics - Doklady* Vol.12, No.11, pp.1040–1041.